Improved Spacecraft Materials for Radiation Shielding

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Summary

Solar particle events and galactic cosmic rays have the potential of producing serious radiation health effects in astronauts in the HEDS (Human Exploration and Development of Space) enterprise. Solar particle events (SPE's) consist mainly of modest energy protons (below a few hundred MeV). Galactic cosmic rays (GCR) consist of high energy particles comprised mainly of protons but also include multiple charged ions (nuclei of chemical elements) through U with only small contributions above Ni. The SPE protons of 30 to 120 MeV are most important to astronaut exposures and fluence levels above 10⁸ p/cm² will limit astronaut activity on rare occasions for a period of several hours to few days. A storm shelter from such events must be provided. The GCR pose an ever-present low level background radiation and have great penetrating power through shield materials. The GCR ions of high charge and energy (HZE) are few in number but dominate the estimated cancer risk to astronauts in deep space. The intensity of these ions must be reduced while holding secondary radiations to a minimum within the spacecraft interior where the astronaut spends most of his time. Unlike the provision of a SPE storm shelter, shielding required against GCR is needed at all times during the mission and greatly impacts mission costs as the shielding of such a large living/work area requires a large mass of material. Of course, the provision of such a large mass for GCR shielding tends to mitigate the SPE storm shelter requirement. The GCR HZE transmission characteristics of shield materials are poorly understood and the estimated excess Mars mission cost for shielding against the GCR due to uncertainty in shield estimates is between \$10B and \$30B. Thus, the provision of shielding from the GCR HZE particles at minimum mission cost is a critical element of the HEDS enterprise. Unless there are cost effective means developed to protect the astronaut, there will be no HEDS missions beyond the geomagnetic field.

The insufficient understanding of HZE particle-induced risk to astronauts is a basic challenge to shield material studies at this time. Cancer induction is related to mutational events in the cell which have been studied in mammalian cell systems as a guide to the effectiveness of HZE particle cancer induction. There also exist data from HZE induction of harderian gland tumors in mice for which models have been derived. These radiobiological models will be used as indicators for the rate of cancer risk attenuation as a function of materials selection and thickness. The second challenge in seeking optimum shielding materials is that models for the nuclear interaction processes (fragmentation and secondary particle production cross sections) required for shield evaluation are not entirely developed and validated. Therefore, laboratory testing of material

transmission characteristics is an essential component of any materials development program. In the testing area, it is impossible to test all materials against all ions in the GCR environment due to the large number of ion types and their broad energy spectrum. Testing is limited to a few dominant ions at the most important energies. Sixty percent of the astronaut cancer risks are from the ions of C, O, Mg, Si, and Fe (with an added 30 percent from the other HZE ions and only about 8 percent from GCR protons). These five dominant ions will be the focus of laboratory testing in the most important energy range between 500 MeV per nucleon and 2000 MeV per nucleon. Such transmission tests require a complex diagnostic apparatus to identify the particles transmitted through or produced in the shield material. A unique test apparatus has been developed and operated for NASA by the Lawrence Berkeley National Laboratory for use at the Brookhaven National Laboratory (BNL) AGS accelerator facility (a unique facility within the U.S. able to simulate the GCR HZE ion beams found in space). Some components produced in an external shield material are themselves biologically damaging (e.g., neutrons) and multilayered neutron absorbing materials may show advantage. A neutron shield testing facility and computational procedures are now available at NASA Langley Research Center for the optimization of neutron absorption properties.

In the execution of this proposal, we will first examine current and developing spacecraft materials and evaluate their ability to attenuate adverse biological mutational events in mammalian cell systems and reduce the rate of cancer induction in mice harderian glands as a measure of their protective qualities. The HZETRN code system will be used to generate a database on GCR attenuation in each material. If a third year of funding is granted, the most promising and mission-specific materials will be used to study the impact on mission cost for a typical Mars mission scenario as was planned in our original two year proposal at the original funding level. The most promising candidate materials will be further tested as to their transmission characteristics in Fe and Si ion beams to evaluate the accuracy of the HZETRN transmission factors. Materials deemed critical to mission success may also require testing as well as materials developed by industry for their radiation protective qualities (e.g., Physical Sciences, Inc.). A study will be made of designing polymeric materials and composite materials with improved radiation shielding properties as well as the possible improvement of mission specific materials.

The choice of materials will be guided as follows. Since aluminum alloys are still the primary construction technology in the space program, we will study the effects of added alloy components as to their protective qualities. For example, the Cu additive to aluminum alloy will lessen the shielding effectiveness whereas Al-Li alloy systems will have improved shielding characteristics. Aluminum metal matrix composites are favorable depending on the fiber used and boron fibers in particular may show some advantage since they absorb low energy neutrons which are always produced as a secondary reaction product. Neat polymers have already shown important advantages in their radiation protection properties and can be ordered in their protective abilities according to their hydrogen content although there has been little laboratory testing. The use of in situ polymer manufacturing and regolith composites will be examined as a mission cost effective means of habitat construction. Polymer matrix composites could be an important alternative to many aluminum-based structures, with anticipated improved radiation protective properties. We will examine the effects of fiber choice on protective properties as well as of polymer content. The protective value of the fibers are expected to be ordered from least effective to most effective as glass, graphite, boron, Kevlar, and polyethylene fibers. In addition, materials identified as part of mission critical elements, such as inflatable lay-ups, regolith augmentation, and consumables, will be evaluated. All of the materials will be quantified as to their protective abilities and trade studies (if funded) in the third year will be made on the most promising materials to evaluate their effect on mission costs in the context of current uncertainty in HZE cancer risks factors. The validity of the predicted transmission properties will be tested in the Fe and Si ion beams at the BNL AGS accelerator. Added beam testing with C,O, and Mg beams will be accomplished if funded.